



<http://www.cfht.hawaii.edu/~cabanac/SL2S/>

# Looking for strong gravitational lenses in the CFHT Legacy Survey

*Raphaël Gavazzi  
&  
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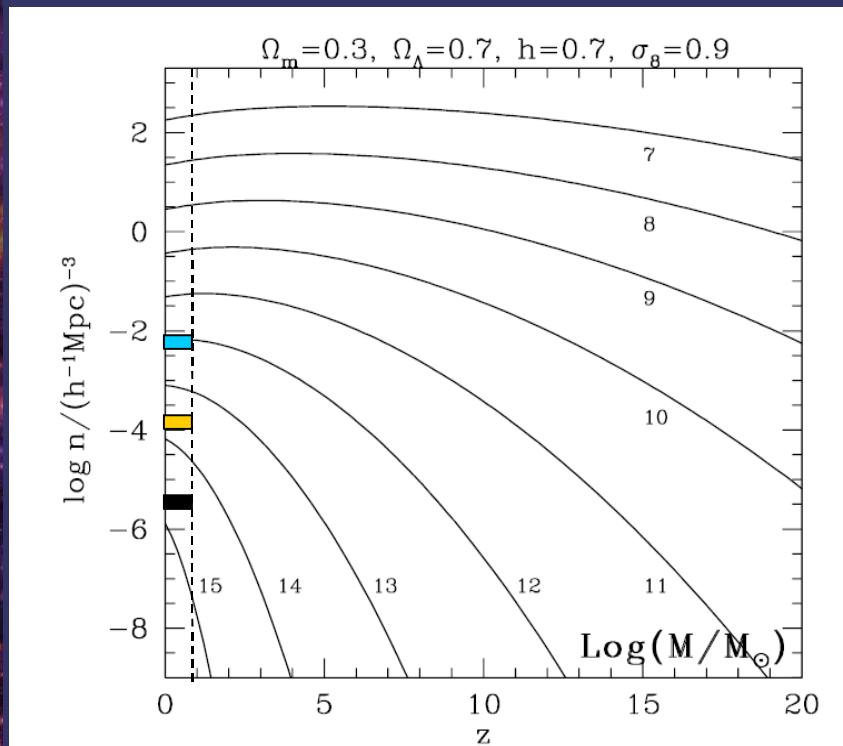
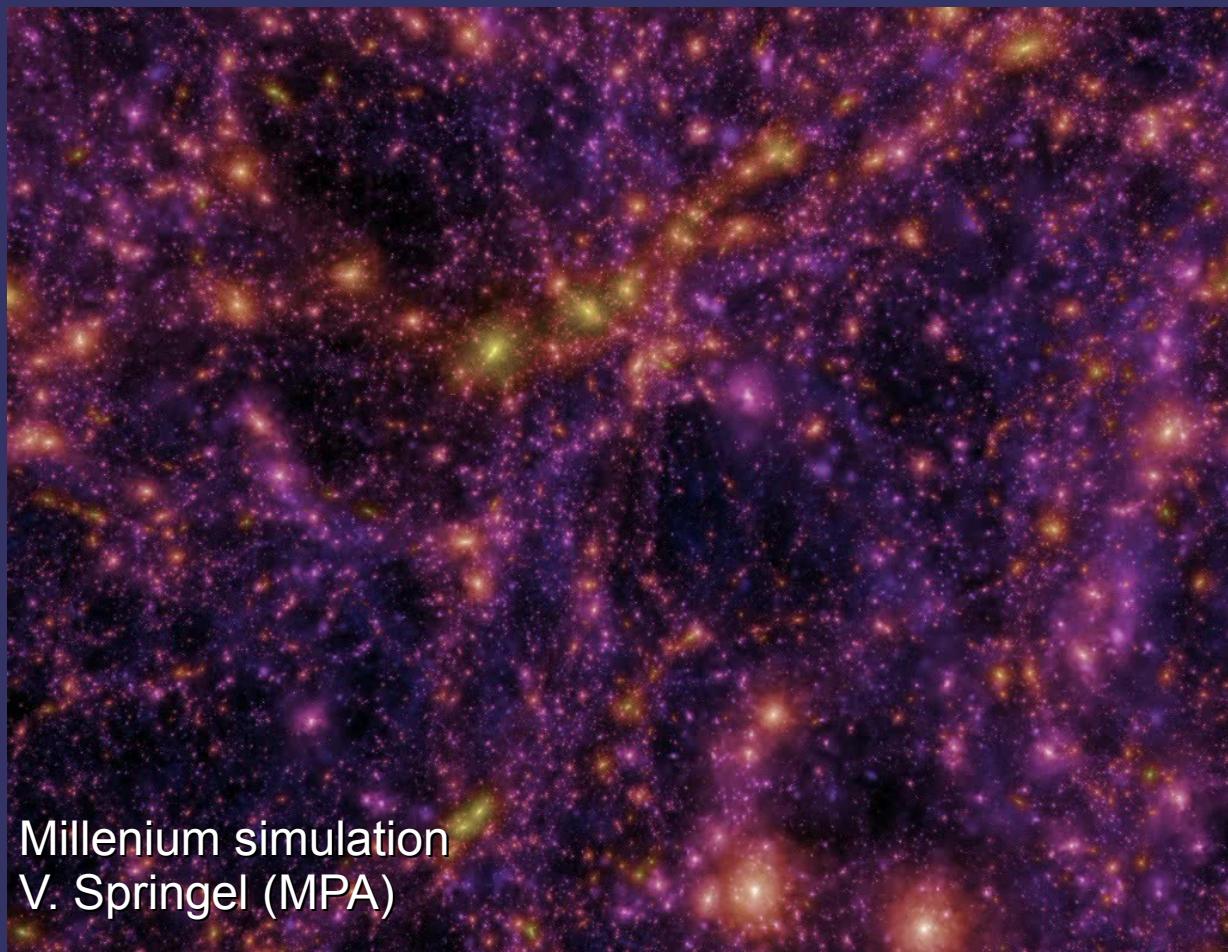
Obs. Midi-Pyrénées  
(France)

## Collaborators:

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S. Jouvel, JP. Kneib, O. LeFevre, A. Leauthaud, M. Limousin, P. Marshall, Y. Mellier,  
R. Pello, G. Soucail, S. Suyu, JF. Sygnet, M. Swinbank, K. Thanjavur, H. Tu,  
D. Valls-Gabaud, J. Willis



# Introduction



*Comoving number density of DM halos  
from Mo & White 2002*

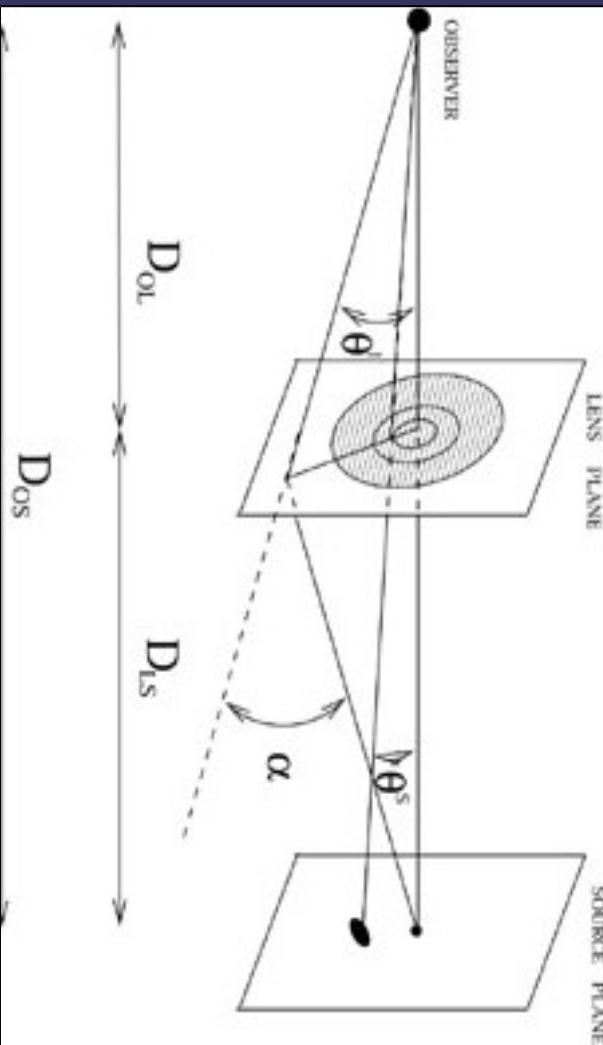
Predicted halo mass function from CDM paradigm

Properties and demographics of lensing structures well predicted

+Add galaxy formation (on small scales)

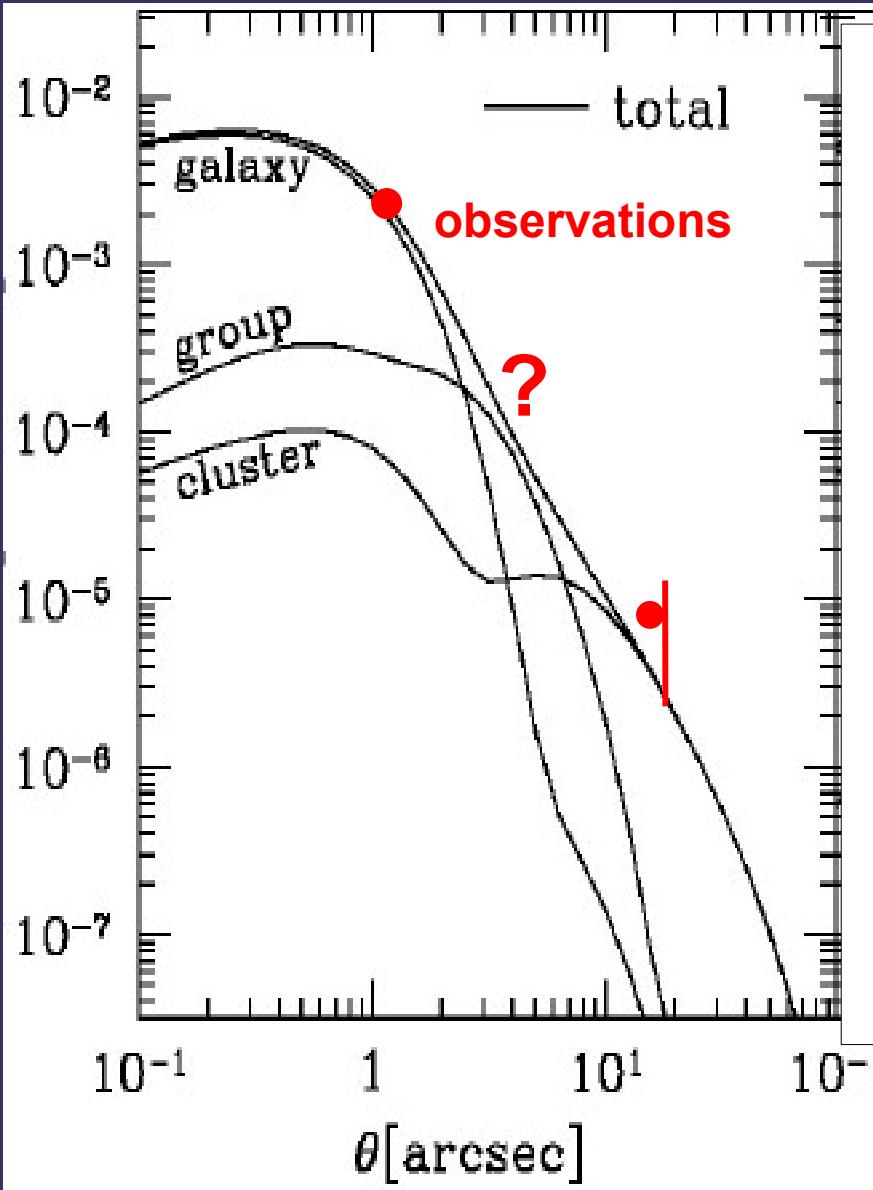


+Hypotheses on population of luminous lensed objects.



$$\vec{\beta} = \vec{\theta} - \vec{\alpha} \equiv \vec{\theta} - \vec{\nabla}\psi(\vec{\theta})$$

$$\psi(\vec{\theta}) = \frac{2}{c^2} \frac{D_{LS}}{D_{OS} D_{OL}} \varphi(\vec{\theta})$$



**Distribution of splitting angles (2x Einstein radius) Oguri 2006**

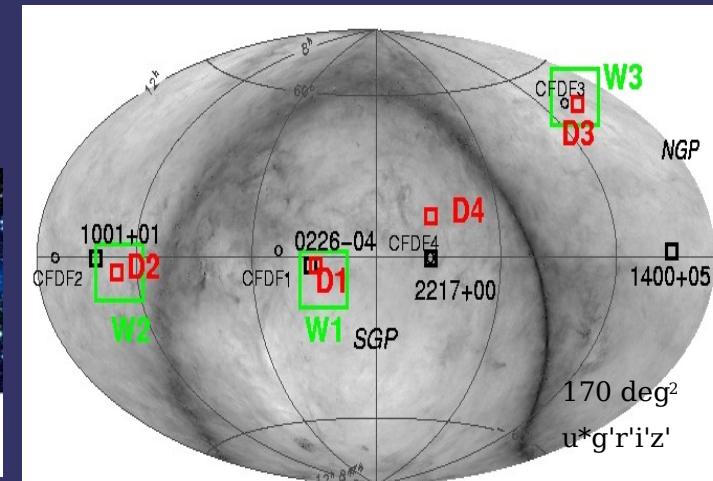
predicted n / 1 sq°	
Rings	-> 10-20
Groups	-> 1-2
Clusters	-> 0.4

expected CFHTLS

Rings	> 1000
Groups	> 100
Clusters	> 50
SHMO	> 300
Others	?

# The CFHT Legacy Survey

- Imaging survey at CFHT 2003-2008...
- Megacam camera (1deg fov, 0.18"/px)
- Good image quality (seeing ~0.85")



## Wide Survey

170 deg<sup>2</sup> (**u, g, r, i, z**), I<sub>AB</sub>=24.5.

3 patches (now 4)



## Deep Survey

4 deg<sup>2</sup> (**u,g,r,i,z**), I<sub>AB</sub>=27.  
Good time sampling (designed for SNe)

## CFHTLS Releases:

T0002: 4deg<sup>2</sup> Deep ugriz (down to I~25.5)  
28deg<sup>2</sup> Wide g r/2 i ( 24.5)

} Cabanac et al. 07

T0003: 4deg<sup>2</sup> Deep ugriz (down to I~26.5)  
40deg<sup>2</sup> Wide g r/2 i

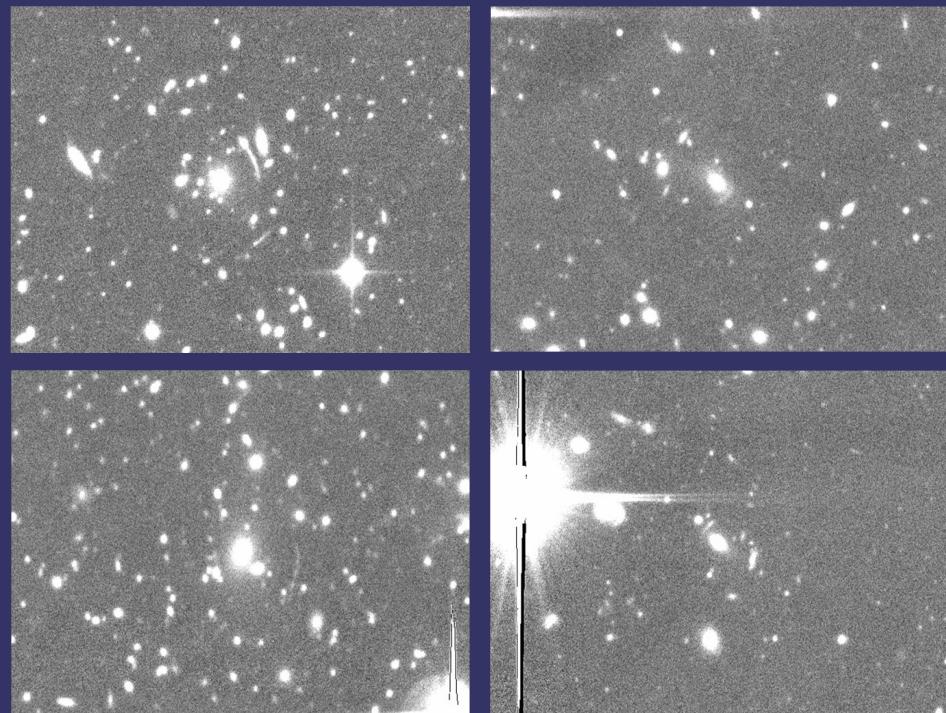
} Being followed-up

T0004 (soon): ... Deep ugriz (down to I~27) + new stacks with 25% best seeing (~0.5")  
Wide 125deg<sup>2</sup> u r/2 i , 25 deg<sup>2</sup> ugriz (means 85 deg<sup>2</sup> new!!)



Visual inspection / serendipitous detection of giant arcs in the CFHTLS:

- Cumbersome !
- Quantitative predictions?
- Reproducibility of results???



(from Mellier 2005)

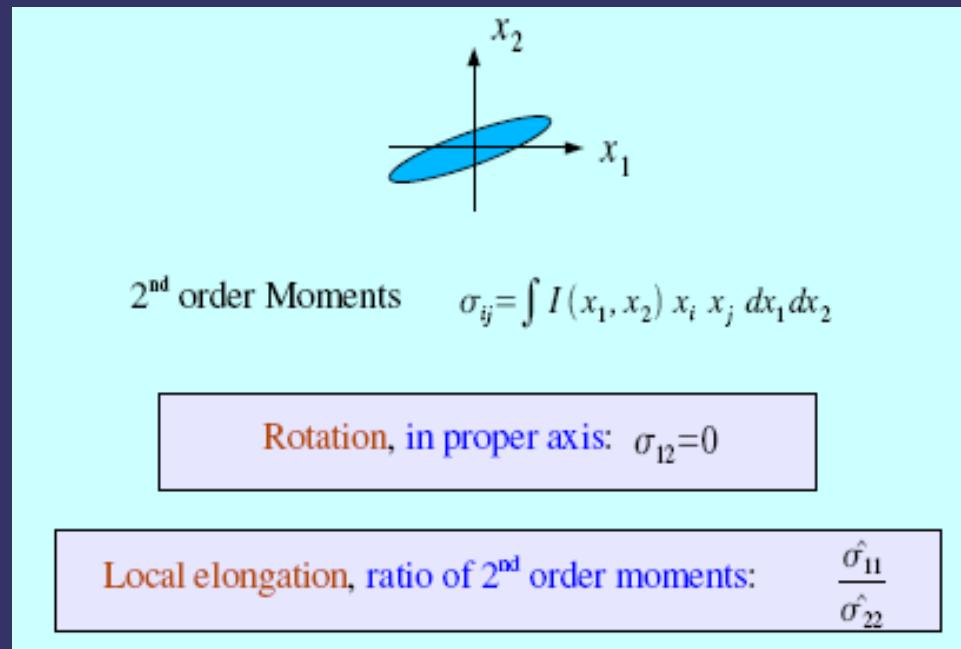
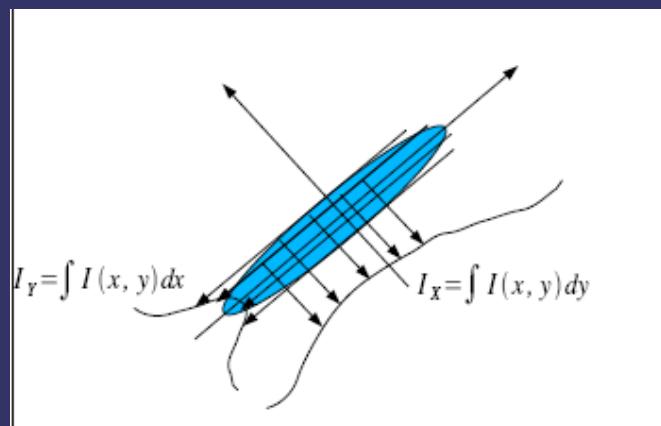
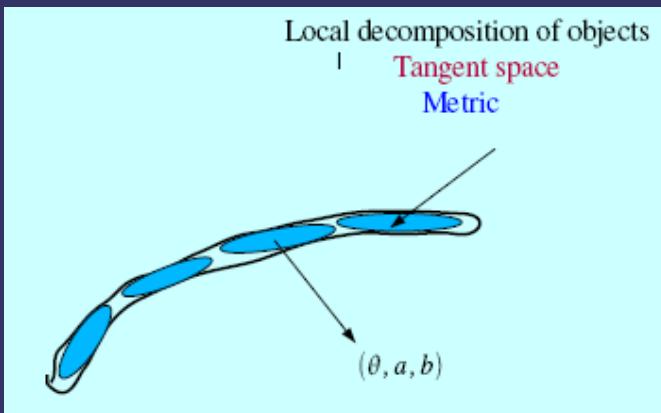
## Automated detection procedures:

Arcfinder (Alard 2006)

Ringfinder (Gavazzi et al, in prep.)



# Geometric description of arcs



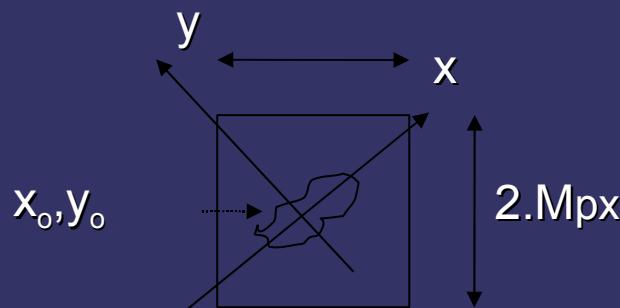
arc thickness  $\sim$  seeing

search a local elongation with  $w=\text{seeing}$



# Arcs detector

Arc reconstruction by a small scale estimator of a local elongation (seeing width) of light distribution



scanning aperture  $M \times M$  pixel unit ( $M \sim 7$ )  
unit, optimal mexican hat filtering  
( $x, y$ ) local axis aligned on second  
moments of light distribution  $\rightarrow E(x_o, y_o)$   
map

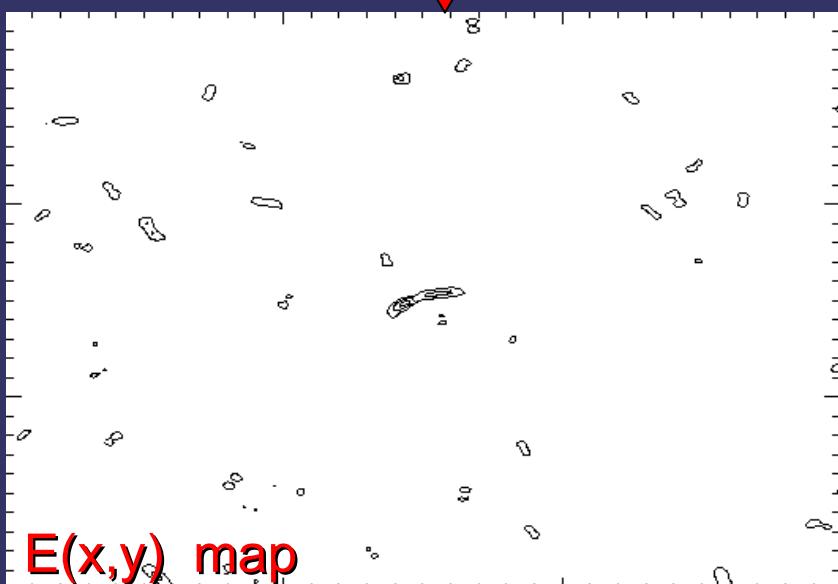
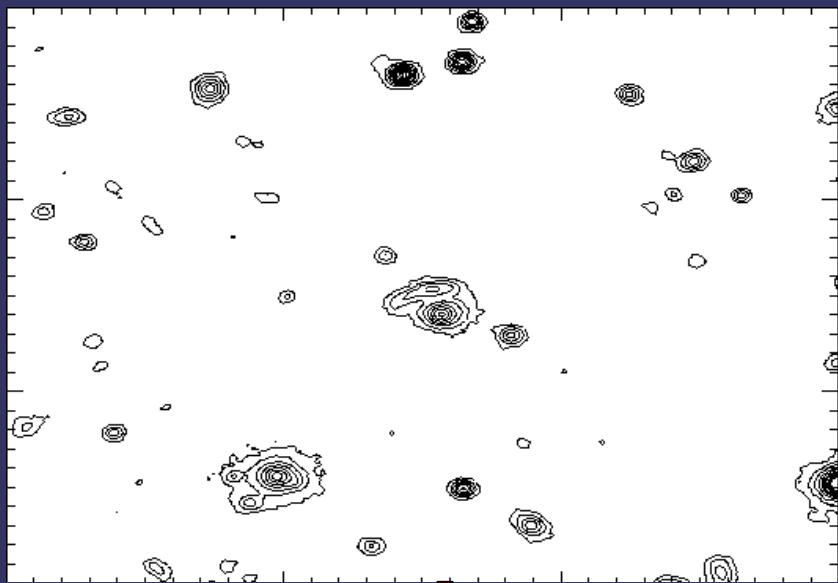
local estimator

$$E(x_o, y_o) = \frac{\int I(x_o + x, y_o) dx}{2.M \cdot \text{Max}_{[-M < x < M]} [\int I(x_o + x, y_o + y) dy]}$$

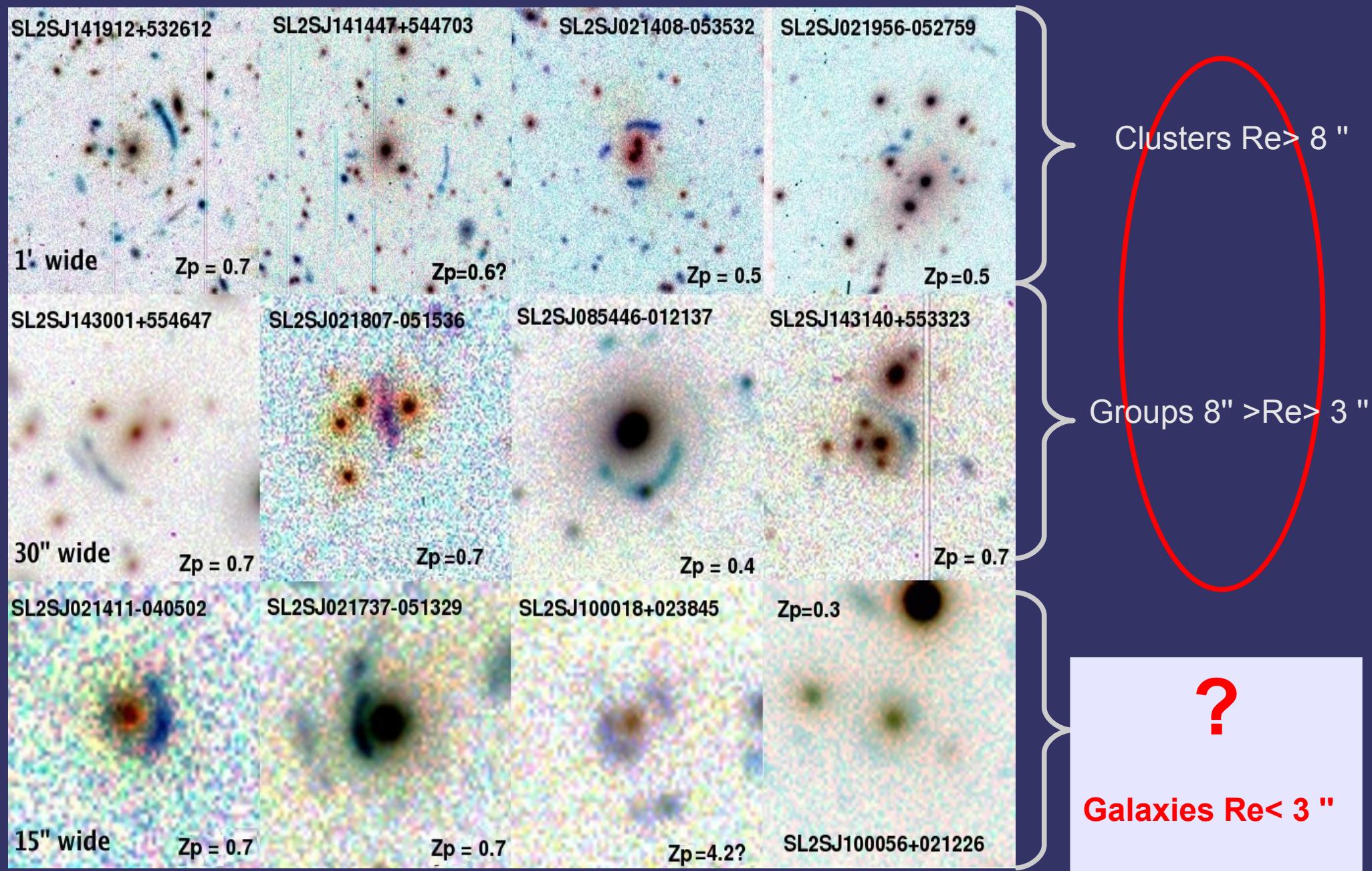


# Detection example

with a typical CFHTLS  
arc candidate



## Cabanac et al. 07



# RingFinder

a) **Lens-oriented:** Needs "targets"

Early-types from multicolor (photoz) ( $i < 22.5$ )

**GOAL:** find faint blue background sources

enbedded in bright red foreground lenses.

b) **Lens subtraction:** Tune  $\alpha$  such that lens vanishes

in a (Blue –  $\alpha$  Red) image and analyse residuals.

c) **Selection in size, shape, orientation, multiplicity**

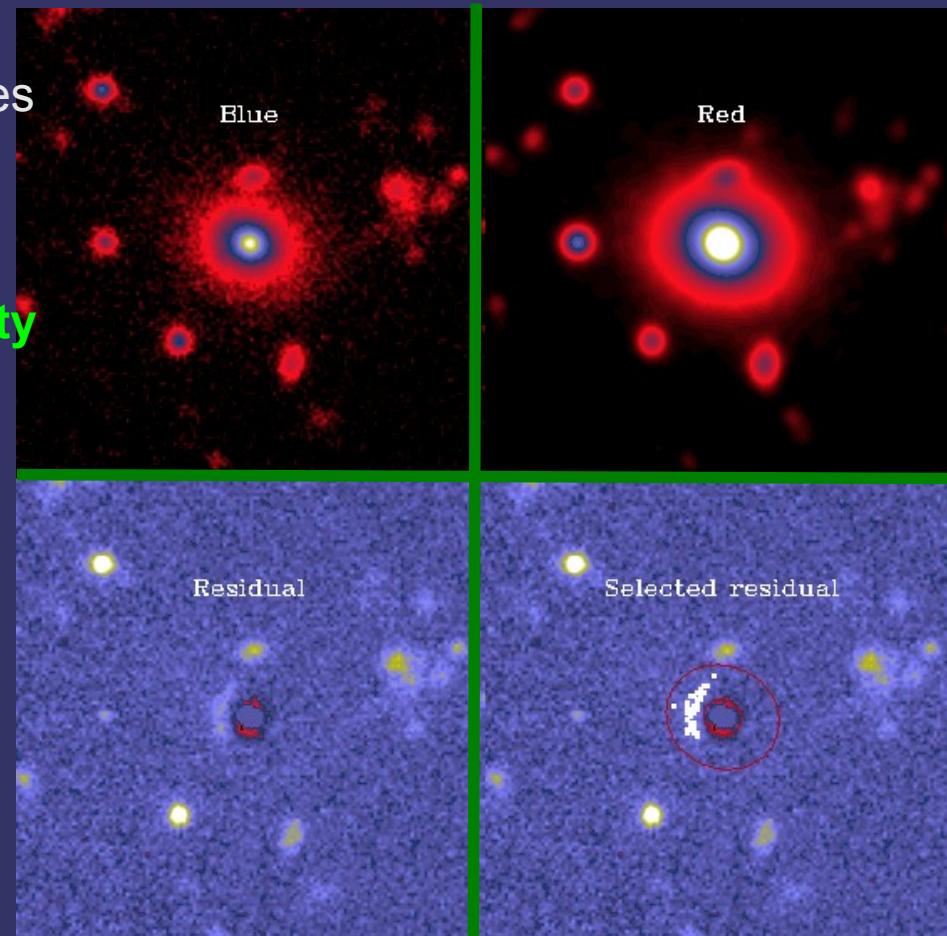
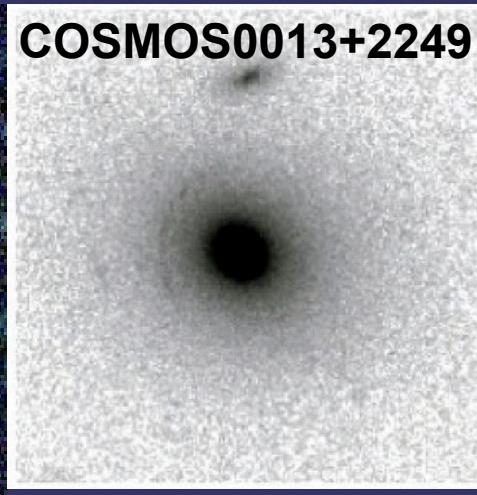
d) **Eyeball classification or direct follow-up.**

Per deg<sup>2</sup> at stage a) 3000 targets

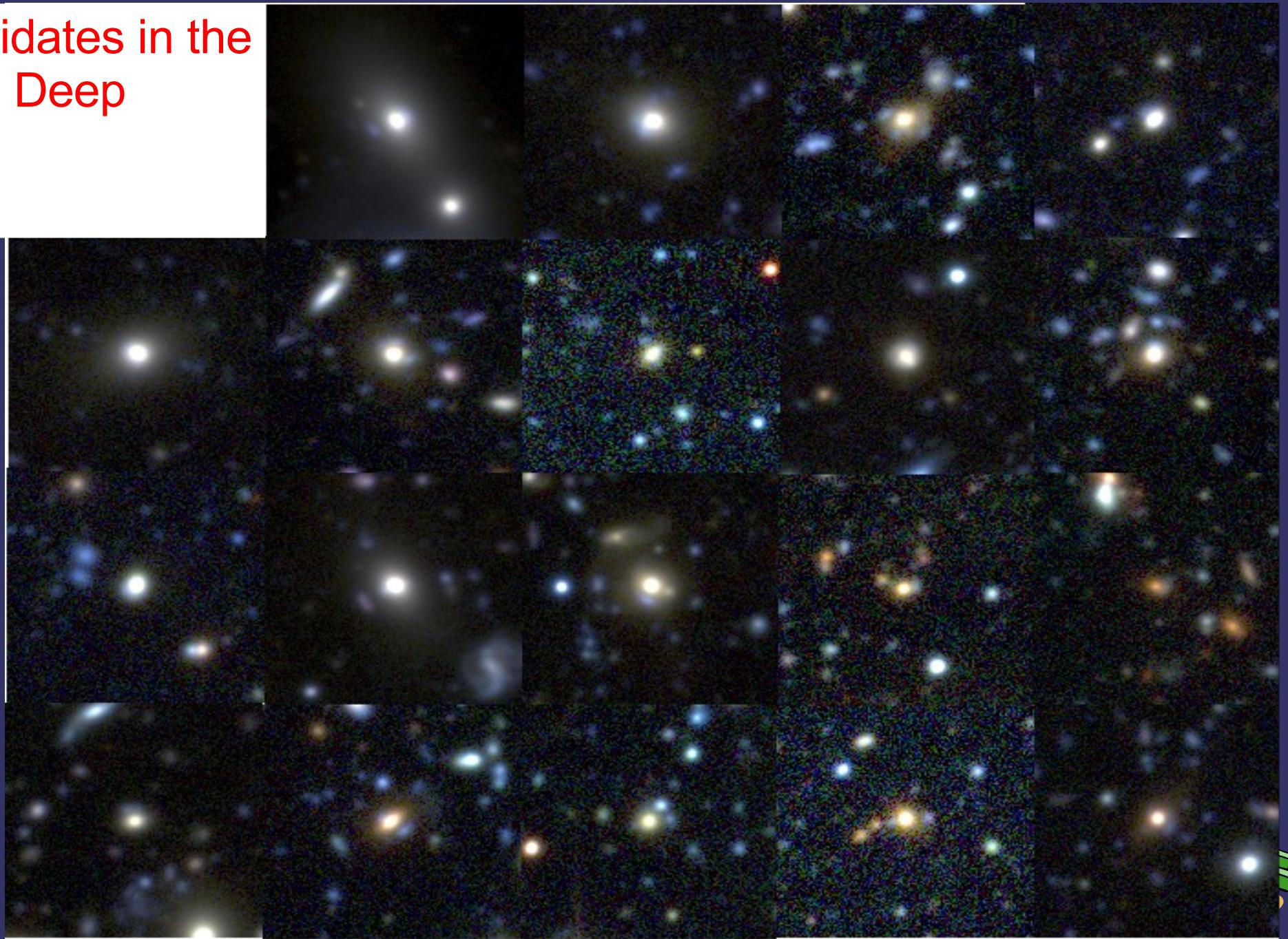
b-c) 50-200 with residuals

d) visual inspection: 20 cand.

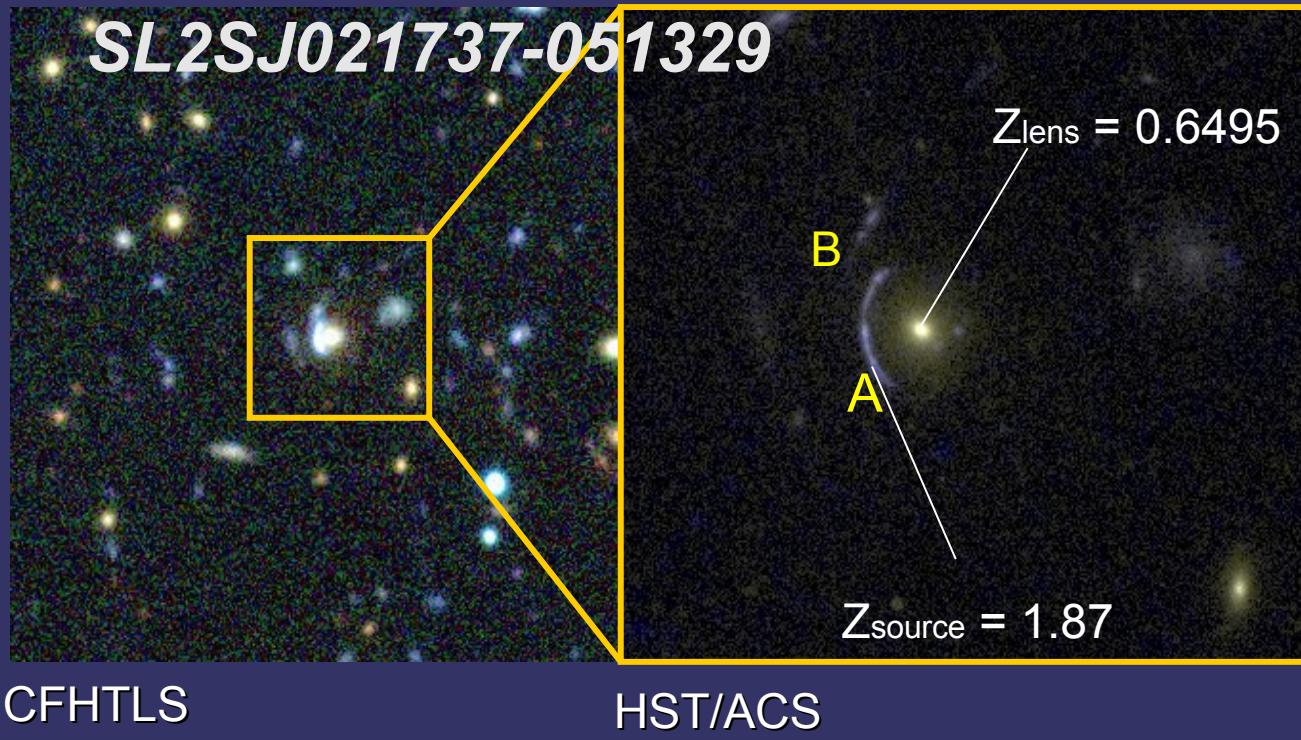
5 serious



# Candidates in the Deep



# Confirmation follow-up



**HST imaging:**

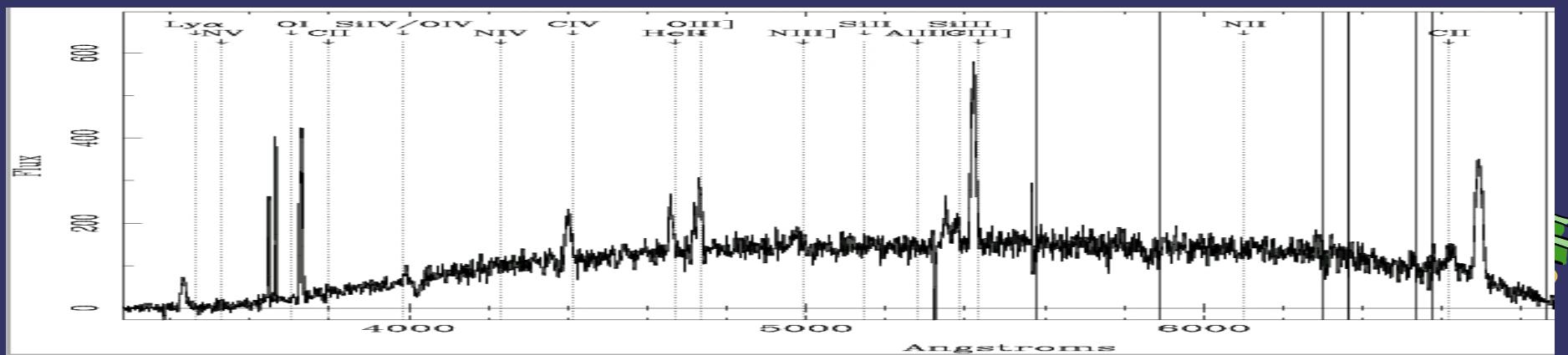
c15: 5 systems (ACS/F814)

c16: 130 snapshots...WFPC2

**Spectroscopy for lens and source redshifts:**

$z_l=0.650, z_s=1.87$

longslit LRIS@Keck



## **Spectro @ Keck and VLT:**

2 Keck nights in Sep 07: redshifts & velocity dispersion (join SL-dynamics à la LSD/SLACS)

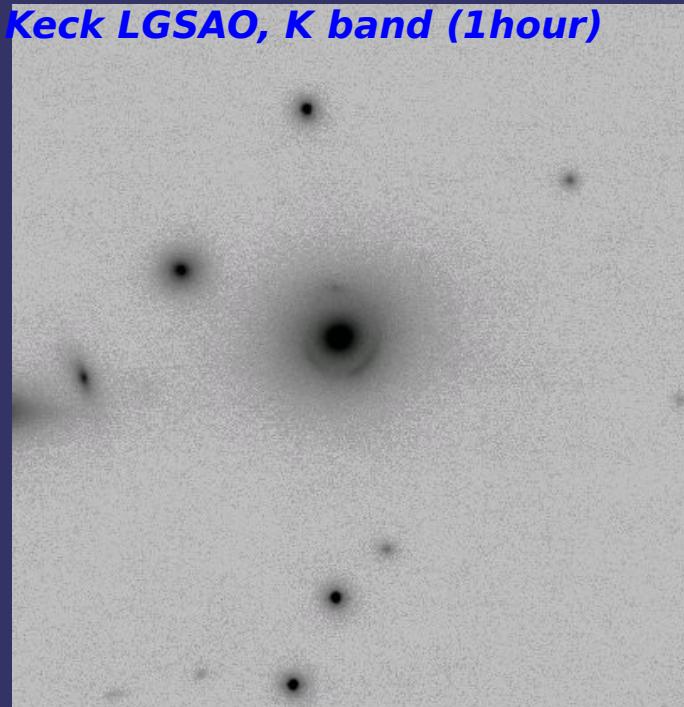
16 hours VLT/VIMOS to test mid-low quality systems with dense masks.

## **LGSАО @ Keck**

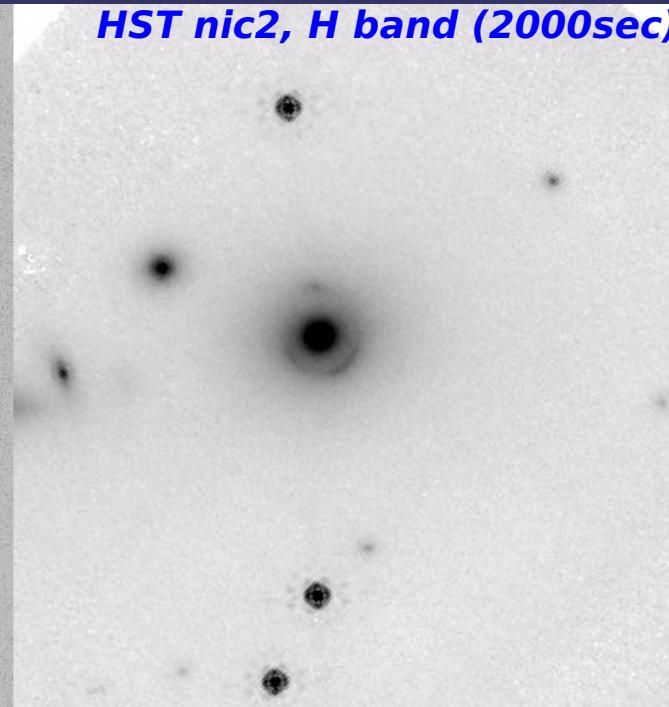
2 nights in Sep 07: ~20 systems confirmed/ruled out?

Pilot study on SLACS system SDSSJ0737+3216:  
Marshall, Treu et al. 07, ApJ submitted

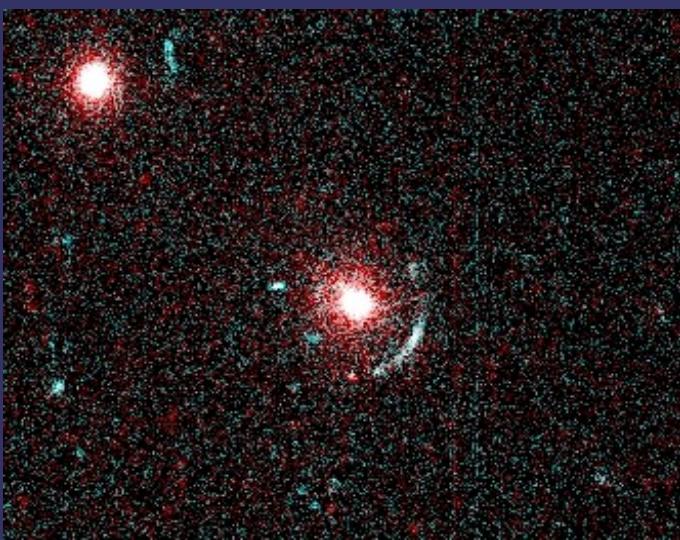
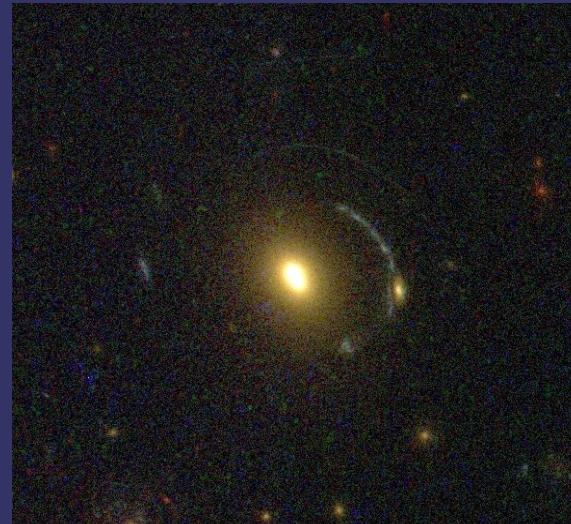
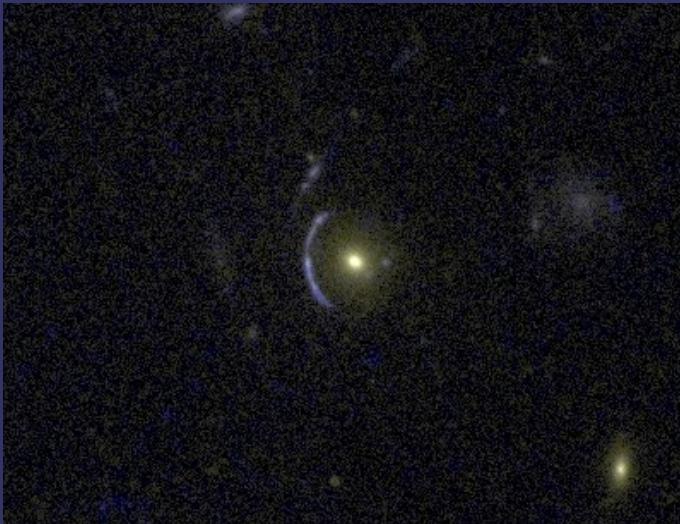
**Keck LGSАО, K band (1hour)**



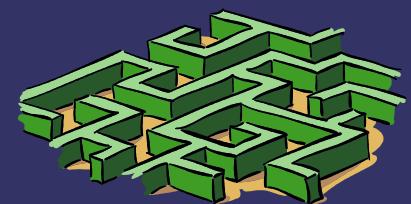
**HST nic2, H band (2000sec)**



## Summary of Cycle 15 HST snapshot observations (before ACS death!!!)



5 out of 5 are actual lenses!



# Comparison to AEGIS

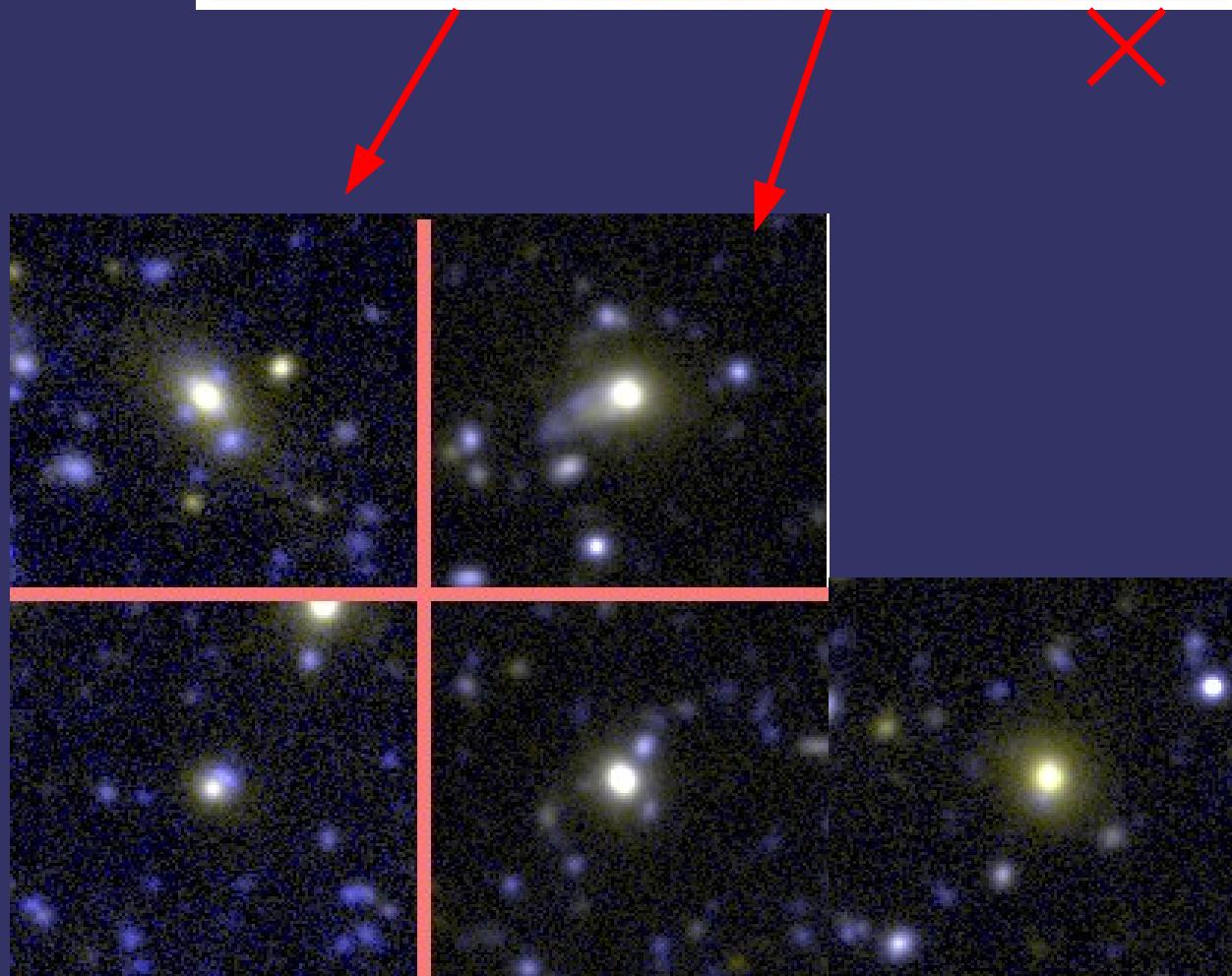
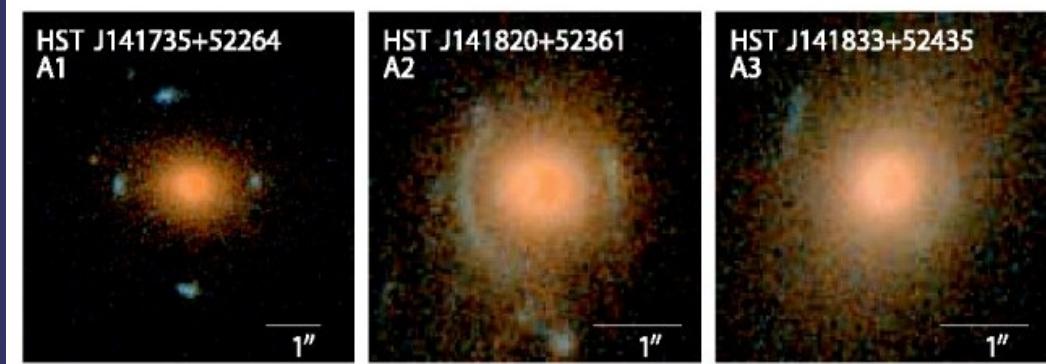
CFHTLS D3 intercepts Groth Strip (~20% of area  $\sim 650 \text{ arcmin}^2$ ).

Out of the 7 published in Moustakas et al. 07 as part of AEGIS

- A3 missed
- B2 missed (faint and in masked area)

Recovered 2/3 ( $\frac{3}{4}$ ) of (un)secure lenses!

More quantitative comparison in progress (also with COSMOS and simulations of mock lenses).



# Main results:

T0002: over  $28\text{deg}^2$ , we found 40 systems.

First important access to groups ( $M \sim 10^{13-13.5}$ )

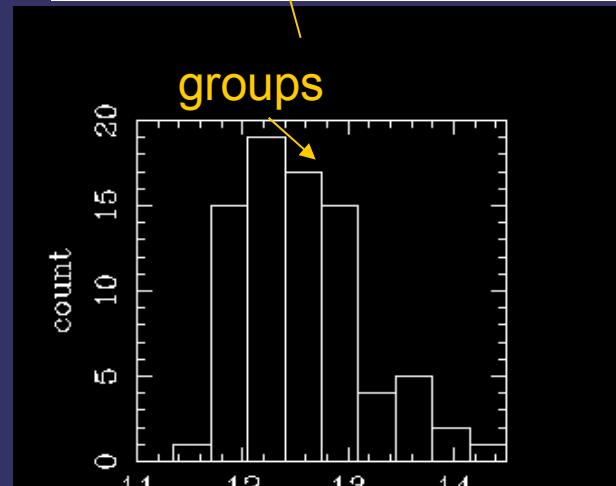
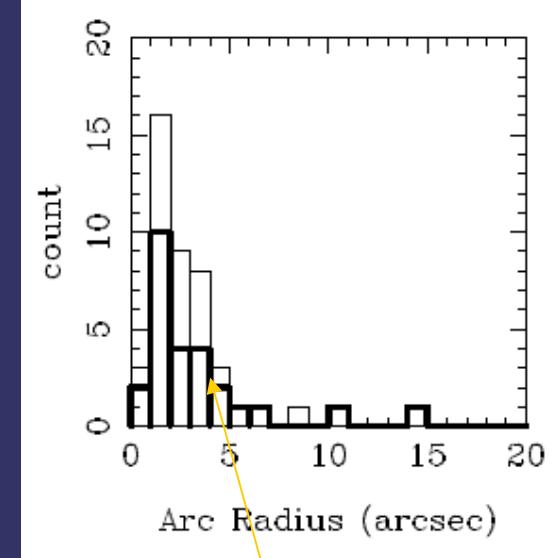
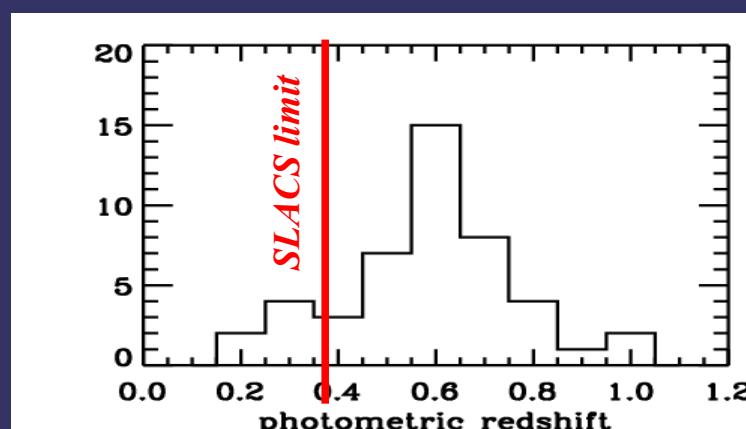
T0003:  $40\text{deg}^2$ ,  $\sim 47$  arcs (groups and clusters)

$> 70$  rings (20 high priority)

*being observed with HST and LGSAO*

more to come with T0004...

**CFHTLS depth allows to find high-z lenses (extends SLACS)**



# Conclusion

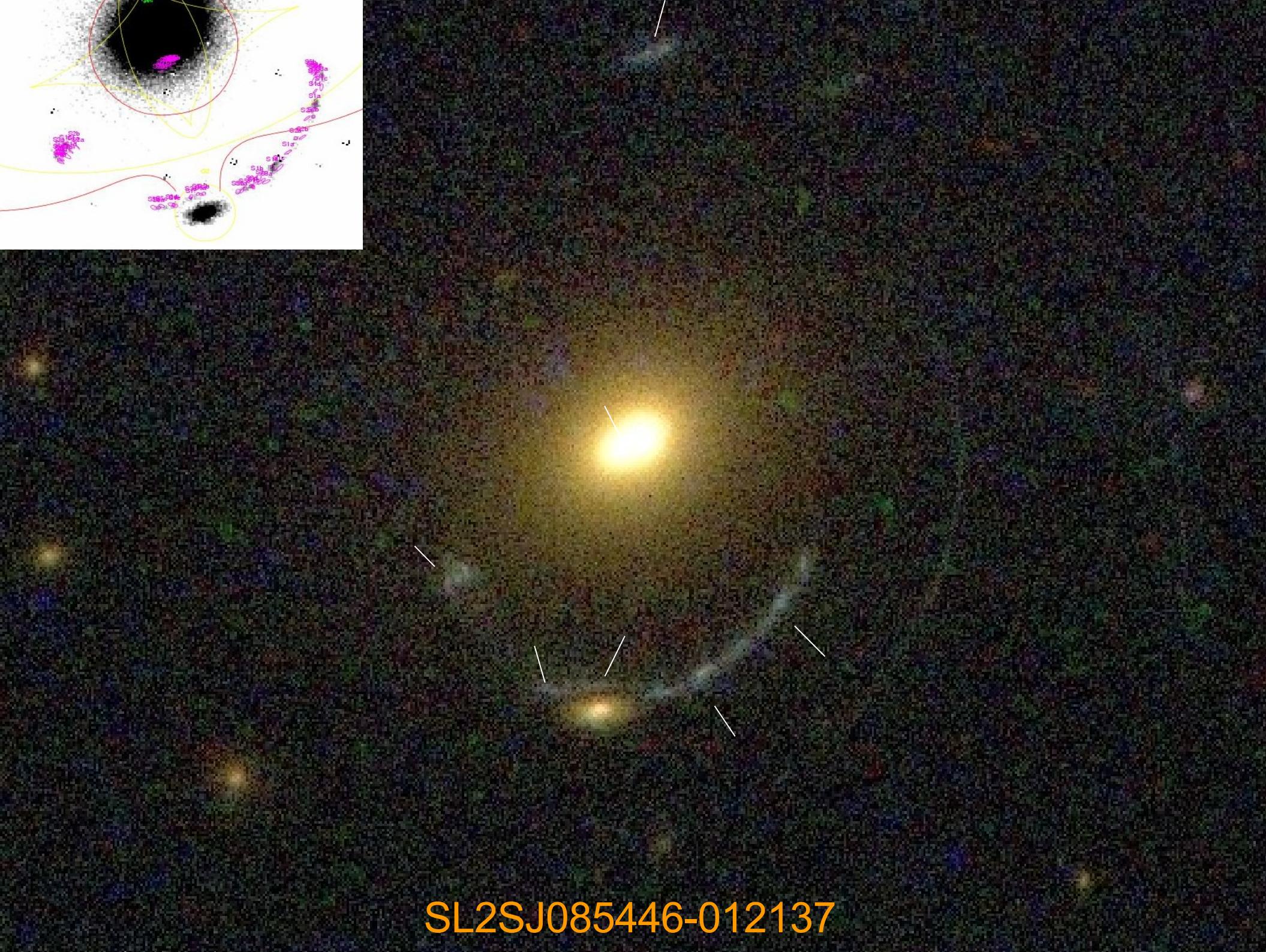
SL2S will be among the largest SL databases for the next 5 years, possibly 1000 SLs (spectroscopy is bottle-neck).

SL2S will extend the lensing studies of galaxy mass evolution at high redshift

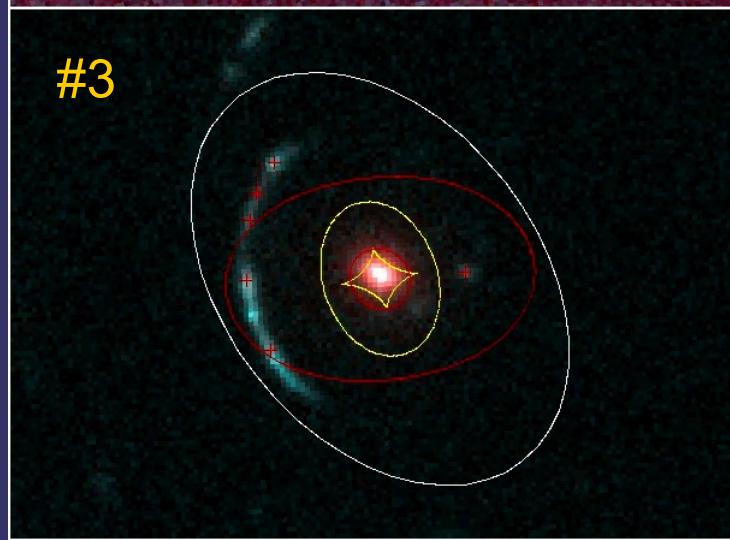
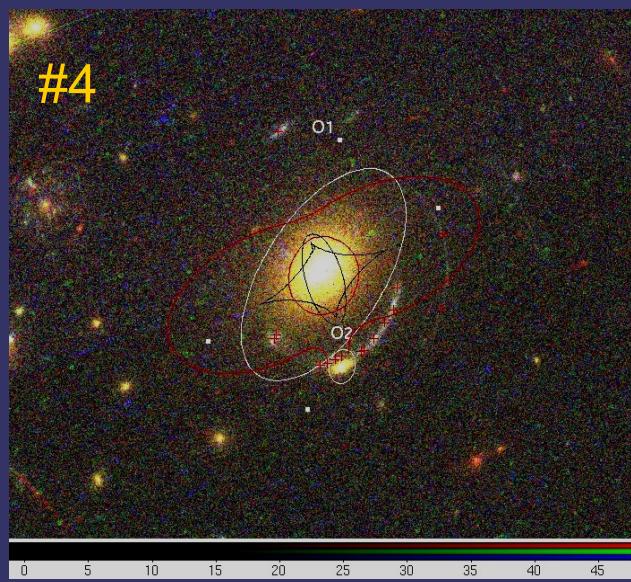
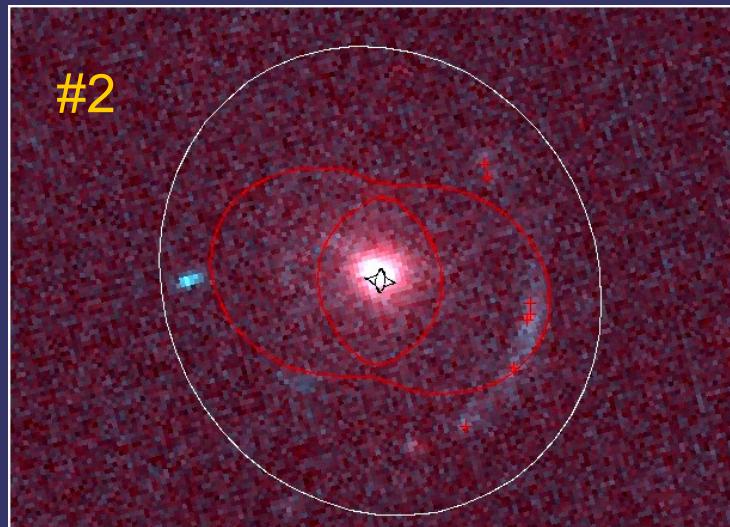
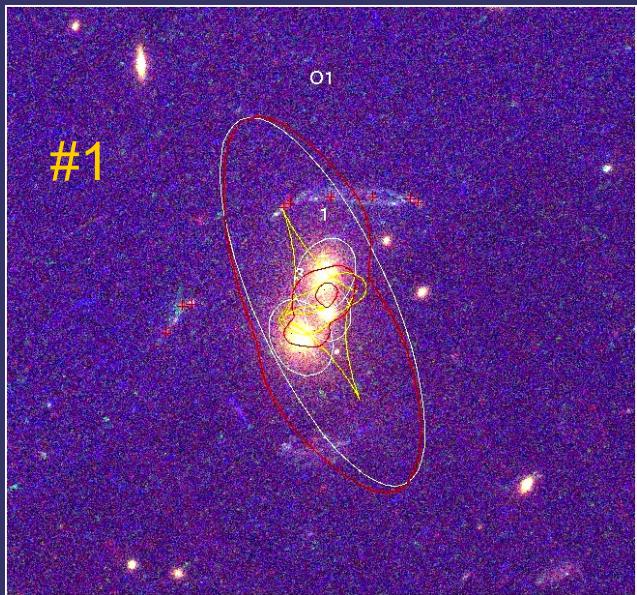
Numerous rings and arcs over a large range of masses. New window on group-scale halos is opened.

SL2S is a step for the preparation of SL analyses with LSST-like surveys.





SL2SJ085446-012137



Fort & Hong

